Using Augmented Reality to Elicit Pretend Play for Children with Autism

Zhen Bai, Alan F. Blackwell, and George Coulouris

Abstract—Children with autism spectrum condition (ASC) suffer from deficits or developmental delays in symbolic thinking. In particular, they are often found lacking in pretend play during early childhood. Researchers believe that they encounter difficulty in generating and maintaining mental representation of pretense coupled with the immediate reality. We have developed an interactive system that explores the potential of Augmented Reality (AR) technology to visually conceptualize the representation of pretense within an open-ended play environment. Results from an empirical study involving children with ASC aged 4 to 7 demonstrated a significant improvement of pretend play in terms of frequency, duration and relevance using the AR system in comparison to a non computer-assisted situation. We investigated individual differences, skill transfer, system usability and limitations of the proposed AR system. We discuss design guidelines for future AR systems for children with ASC and other pervasive developmental disorders.

Index Terms—Augmented Reality, pretend play, children, autism

1 Introduction

Lack of imagination has been identified as one of the major symptoms that constitute the triad of autism spectrum condition (ASC) characteristics [36], together with impaired social interaction and communication. In particular, pretend/symbolic play is an important diagnostic indicator of childhood autism as defined by ICD-10 [19] and DSM-IV [1]. Pretend play appears in the latter half of the second year among normally developed children and is closely related to critical developments such as symbolic thinking, language and social interaction [27]. In addition, it is believed that pretend play is closely related with the ability to understand other's mind [4], which has profound influence in one's adult life [24].

Smilansky described pretend play as substituting an imaginary situation that satisfies one's personal wishes and needs [34]. Such imaginary situations are summarised into three forms [24]: object substitution (e.g. pretending a banana is a telephone); attribution of absent properties (e.g. pretending a toy oven is actually hot); or presence of imaginary objects (e.g. holding an imaginary toothbrush). What makes pretend play different from other literal forms of play is that it relies on dual representations of reality and pretense. For example, Piaget argued that the mental image of an absent object assimilated to a present object is evoked during pretend play [27]. Nevertheless, such voluntary coupling between the pretense and reality is absent or inhibited among children with ASC.

AR technologies empower people to better understand their surroundings by combining reality with virtual contents in meaningful ways. This capability motivated us to explore the potential for using AR to interpret the real world in a symbolic and nonliteral manner in a play situation. As demonstrated in Fig. 1, we hypothesised that AR could support the mental representation of pretense by presenting a reflection of the world in which a simple play object (a wooden block) is replaced by an imaginary alternative (a car). The augmented car tracks the position of the block in the scene, so that the child can manipulate imaginary scenarios that are also visibly represented. The visual rendering of the otherwise invisible imaginary world supports the child to carry out actions in non-actual situations and extend them in novel ways.

Motivated by this hypothesis, we designed and developed an AR system[3], followed by an empirical study assessing the effectiveness of the AR system in promoting pretend play for children with ASC, as compared with a non computer-assisted situation. The experiment results confirm that the AR system can help participants to carry out pretend play more frequently, maintain longer pretend play duration and keep their play ideas more consistent to suggested themes. Based on the analysis of individual differences in terms of minute-by-minute play behaviour as well as the nonliteral use of non-augmented objects, we suggest a gradual level of effectiveness according to individual's autistic condition. We also observe a positive skill transfer from the AR system to the non computer-assisted situation. Insights of usability and design guidance are discussed to inform the design of future AR system intended for related user groups.

2 Related Work

Research shows that children with ASC may carry out some pretense actions under specific instructions [22]. For example, the therapist may demonstrate a pretense action by pushing a block into a shoe box while saying "push the car into the garage". Such behavioural intervention approaches

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Manuscript received 15 Jan. 2014; revised 10 Nov. 2014; accepted 14 Dec. 2014. Date of publication 30 Dec. 2014; date of current version 1 Apr. 2015. Recommended for acceptance by M. Gandy, S. Julier, and K. Kiyokawa.
For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org, and reference the Digital Object Identifier below.
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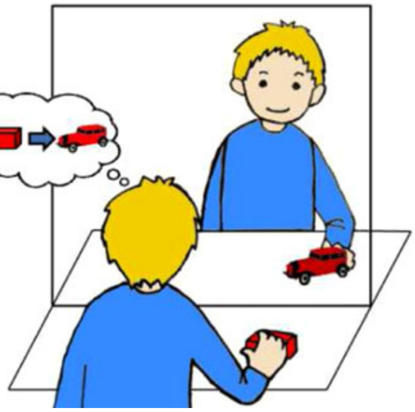


Fig. 1. In reality the child holds a block in his hand. In the AR display, an imaginary car overlays on the block.

have shown moderate effectiveness [2]. One major concern, however, is that children may simply imitate the modelled behaviours, without forming original play intentions as normal children do [25]. We hoped that AR approaches would increase the intrinsic motivation of autistic children engaged in pretend play.

Although we are not aware of an AR system specifically proposed for encouraging pretend play for children with ASC, there is an emerging focus on the design of AR systems for children with special needs. Several systems aim to encourage social interaction among children with ASC [13], [14], [35] and learning or physical disabilities [9]. Other systems have been proposed to teach daily life knowledge [18], [30] or enhance motor and cognitive perception [10], [12]. Radu and MacIntyre [28] provided a timely review of AR usability issues raised by special developmental capacities of young children. This provides a solid basis for designing AR systems for children. With regard to our theoretical goal of promoting symbolic activities for children with ASC, Herrera et al. [16] proposed a Virtual Reality (VR) system to teach symbolic transformation of objects seen in real life scenarios such as supermarkets. The transformations were demonstrated in an embedded video format. Positive effect in symbolic understanding was reported based on a small group experiment involving two children. We believe that compared to this VR system, AR technology can further encourage imaginative activities by allowing children to interact directly with physical props, as they do in natural play.

Fig. 2. A participant is interacting with the AR system.

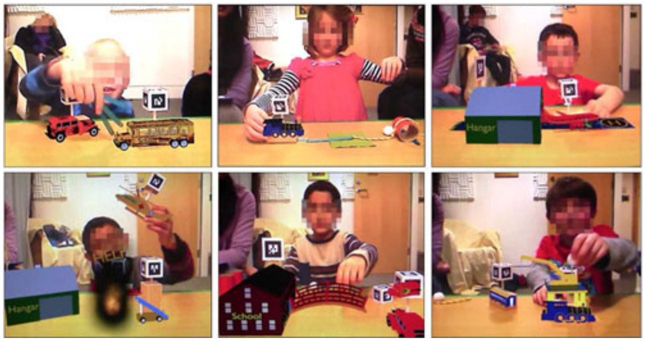


Fig. 3. Participants interacting with the AR system with the car, train and airplane themes.

3 System Description

3.1 System Design

The AR system has been designed on the metaphor of a mirrored view of reality enriched with AR augmentations, as demonstrated in Fig. 2. We chose the mirror metaphor mainly because it allows users to interact with the system without wearing or holding the display equipment and manipulate physical toys with both hands.

We chose car, train and airplane as the play themes because autistic children often show an obsessive interest in machinery [6]. Fig. 3 shows children interacting with the AR system in these different vehicle themes. Each theme incorporates three types of augmentation intended to encourage progressively more complex pretend play behaviors. The vehicle related augmentations are summarized in Table 1.

The first type of behavior is spontaneous engagement with the system. The corresponding augmentation, wherein we overlay vehicles on the blocks, is designed to encourage basic actions towards the substituted object (e.g. drive the block on the table). To increase engagement with the system, additional visual stimuli are added to the vehicle overlays, such as spinning propellers and rotating tires. The second type of behavior is the development of more complex, situationally appropriate play ideas involving multiple augmented toys. The augmentations provide vehicle-related props that encourage these actions and ideas (e.g. drive the

TABLE 1
Summary of AR Objects Augmented on Blocks (Blk), Box (Box) and in the Environment (Evt)

	Blk1	Blk2	Blk3	Box	Evt1	Evt2
Car	car	school bus	petrol	school	bridge	dusty
Train	train	carriage	light	station	track	crane
Plane	plane	helicopter	stairs	hangar	runway	fire

block into the train station, or fill the block with petrol). The third type of behavior is to mix non-augmented toys into the play scenarios, thus extending the augmented play ideas on to non-augmented, open-ended props. The types of additional props provided include pen lids, cotton balls, popsicle sticks, a square of felt, and other similar nondescript items. Such items are frequently used in pretend play experiments, in part because it is easier for the child to inhibit the original function of these objects when performing object substitution. To encourage this third type of behavior, we developed a series of virtual props that are compatible with the vehicle theme. For instance, in the airplane theme, the helicopter is in fact a rescue helicopter, and we provide a virtual fire with a cry for help so as to encourage the child to act out a rescue scene, hopefully involving some non-augmented props—for example, pen lids might be used to play the role of those in need of rescue. The experimenter can dynamically switch between vehicle themes and show/hide augmentations registered in the environment (Evt1 and Evt2 in Table 1) during the experiment.

3.2 System Implementation

Marker-based tracking is commonly used in AR applications (e.g. [15], [26]). The two primary concerns which informed our decision to use marker-based tracking are flexibility of object choice and avoidance of hand occlusion. Unlike model-based tracking which requires pre-built 3D models, marker-based tracking can easily extend the choice of objects to be tracked. Marker-based tracking can also limit the impact of hand occlusion by offsetting the marker placement from the main body of the object. The system is based on a locally modified version of Goblin XNA [20] and the ALVAR tracking library [21]. The approximate system frame-rate is 30 fps. Augmentation jitter was a problem in early prototypes which we minimized by applying the double exponential smoothing method in Goblin XNA.

The configuration file that informs the system of the AR and virtual objects contains three scenes (car, train, and airplane). Each scene contains two lists of objects: (1) AR object list maintaining a list of AR objects, each one associated with a fixed number of markers and a virtual object. Among all detected markers of the same AR object, the system will select the one with the biggest area and retrieve its position and orientation. It then superimposes the coupled virtual object on the AR object accordingly. (2) Evt object list maintaining a list of virtual objects to be augmented on the table surface (e.g. train track). Those virtual objects are statically registered with a calibration marker instead of a physical marker placed on the table in order to avoid occlusion (e.g. move a block along the train track). Prior to the experiment we place the calibration marker in the middle of the table and record its transformation matrix, and then remove the marker. During the system runtime, virtual objects in the Evt object list will be registered according to the position and orientation of the calibration marker. The experimenter can show/hide/switch the Evt objects by pressing hotkeys with a mini Bluetooth keyboard.

The attachment of markers to each AR object is illustrated in Fig. 4. The attachment method is designed to keep a high degree of freedom in tracking and minimize the chance of marker occlusion between these AR objects when aligned in front of the camera.

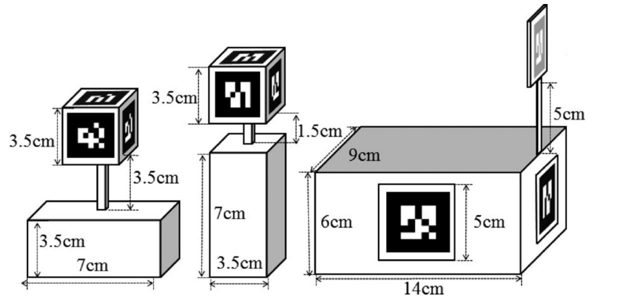


Fig. 4. The marker installation and unit mapping between physical and virtual objects.

4 Expert Feedback and Pilot Study

We demonstrated the prototype system to several psychology experts and received much positive feedback. A pilot study was conducted to test whether normally developed children in the target age group could interact successfully with the AR system. The study invited four neurotypical children as subjects (two boys, two girls, average age 58.6 months) because children of this age are highly engaged with pretend play, while potential usability issues of AR systems dedicated for such low age groups remain largely unexplored.

Overall the pilot study confirmed that hand-eye coordination of neurotypical subjects in the chosen age range is sufficiently developed to enable them to use the AR system. They had no difficulty performing object manipulation in the AR scenes such as grasping, moving, rotating and positioning an AR object relative to another object. They had slightly more difficulty locating augmented objects relative to another object represented entirely virtually, as for example in moving a block visualized as a car over a virtual bridge. We hypothesize that this was due to the absence of haptic feedback and to difficulty with depth perception in the mirrored AR view.

We made several improvements to the system design based on our observation during the pilot study. (1) We added additional situational cues in each scene (e.g. school bus/building, train station, rescue helicopter and fire) to encourage more vehicle-related pretend play; (2) One participant in the pilot study was very interested in how virtual objects were shown on the display. Considering that autistic children are likely to be interested in computer technology, we added a familiarisation session before the main tasks. The participant sees virtual rectangles in different colors augmented on the AR objects (See Fig. 5). They are then allowed to explore freely for up to five minutes to get familiar with the technology; (3) We chose to keep colors consistent for physical props of the same type to avoid color matching play; (4) We replaced props using "interesting" materials with similar ones made of plainer material (e.g. hair rollers covered by velcro were replaced by kitchen towel rolls) to avoid simple manipulation out of pure sensory curiosity.

5 Experiment Design

We designed a within-subject experiment to examine the positive effects of the AR system in promoting pretend play

Fig. 5. The participants explored the AR system in the familiarisation session.

for young children with ASC, compared with a non-computer setup. The experiment consists of two conditions: AR and non-AR. The order of the two conditions is counter-balanced among subjects. There is a short break between the two conditions. In each condition, there are three tasks and the order is randomized. The null hypotheses of the experiment are:

H0A. There is no significant difference in the frequency of pretend play between the AR and non-AR conditions.

H0B. There is no significant difference in the duration of pretend play between the AR and non-AR conditions.

The design of the experiment is largely informed by the rich literature of empirical studies in autism research ([5], [8], [11], [22], [23], [31]). Previous research divides the degree of prompting pretend play into two categories: elicited and instructed. In the elicited prompt scenario, the experimenter encourages the participant to play with available props, without giving specific pretense ideas. An example prompt is "Show me what you can do with these". In the instructed play scenario, the experimenter makes verbal or physical prompt by asking the participant to perform/mimic specific actions, such as "park the car (toy) in the garage (shoebox)". Research has indicated that non-specific elicitations increase pretend play of children with ASC to some extent while specific instructions prompt them to produce as many pretend play episodes as children in the control group [22]. Instructed prompts, however, always require caution in interpreting a child's behavior as pretend play because the child may just make an "intelligent guess" [7] when asked to carry out certain pretend play actions with limited available props. We adopt the elicited prompt strategy in the design of our experiment, because the AR system is intended to encourage open-ended pretend play without detailed instruction of play actions.

5.1 Participants

Twelve children formally diagnosed with ASC or Asperger Syndrome aged 4-7 participated in the study, 10 male and two female. Participants are recruited via the Cambridge Autism Research Center parent mail-list, the newsletter of the Cambridge branch of National Autistic Society, and local autism events. The experiment is approved by the University of Cambridge Ethics Committee. All participants were remunerated with an age appropriate educational gift.

We visited participants' homes prior to the experiment to collect information about their autism and language conditions. We use the Childhood Autism Rating Scale, second edition (CARS2) based on parent interviews and direct observation to inform participants' autism severity. We also evaluate their verbal mental age using the British Picture Vocabulary Scale, third edition (BPVS3). Table 2 shows the participants' information.

TABLE 2
The Summary of Participants' Information

	Chronological Age(months)	Verbal Mental Age(months)	Autism Severity
Mean	82	73*	33.3 (mild-to-moderate)
SD	11.09	17.82	6.34
Rage	53-93	45-104	22.5-41.5

* *One participant was not able to complete the BPVS3*

Based on the CARS2 parent interview, the level for "object use in play" among participants is between mildly and moderately inappropriate (except one participant who was reported as age appropriate). The levels of pretend play frequency at home are frequent (three participants), sometimes (four participants), seldom (four participants) and never (one participant). All participants are familiar with computer devices. Most of them use computers on a daily basis.

5.2 Apparatus

The apparatus in the AR condition contains a 24-inch monitor, a Logitech webcam Pro 9,000 (field of view 75 degrees), a mini Bluetooth keyboard, a table (45*90*45 cm), and play materials. There are two types of play materials including AR objects (three foam blocks and a cardboard box with markers attached) and a set of non-AR physical props (three cotton balls, two paper tubes, three popsicle sticks, three pen tops, three strings and a piece of cloth). The detailed description of the setup is shown in Fig. 6.

The AR objects are located in area "A" and the non-AR props are located in area "B". In addition, we taped out a trapezoidal area on the table to emphasize the range of the camera view. The computer connected to the monitor and webcam is located in another room next door to avoid potential distraction to the participants. The non-AR setup contains the same table and physical props, plus blocks and a box of the same dimensions but without markers. In both conditions we asked the participant to play within the taped area.

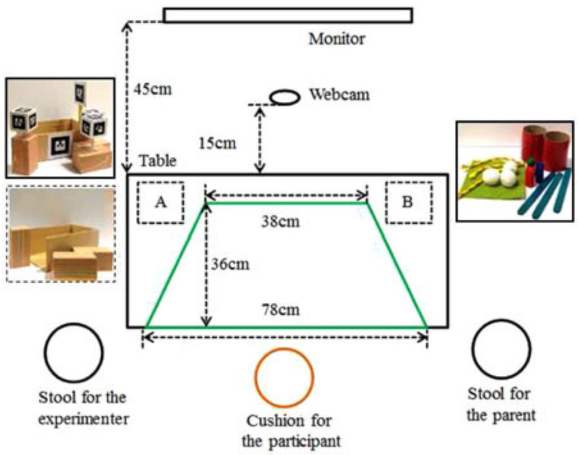


Fig. 6. The physical setup of AR and non-AR conditions.

5.3 Procedure

The main experiment procedures and scripts are consistent in both the AR and non-AR conditions:

1) A brief introduction: the experimenter reminds the participant to *"play inside of the taped area"*, *"play with anything s/he likes on the table"* and *"stop after five minutes"*.
2) Initialize the play materials on the table.
3) Start the task: the experimenter holds one block and asks: *"show me how you can play with this block as a car/train/airplane"*, then gives the block to the participant.
4) During the task:
   a) The experimenter shouldn't give any detailed pretend play ideas.
   b) If the participant doesn't attend to playing, the experimenter should encourage the child by saying: *"I want to see more how you can play with the block as a car/train/airplane. Let's try some more"*.
   c) If the participant doesn't use any of the physical props, the experimenter should encourage by saying: *"You can play with anything you like on the table"*.
   d) The experimenter can prompt a maximum of three times. After that the experimenter should ask: *"Do you want to continue with the play or change to another one"*.
5) After five minutes, the experimenter should wait until the participant finishes with the current play episode and say *"Very good. Now let's stop and put everything back"*.
6) Repeat steps 2-5 for the other two tasks.
7) Ask the participant for feedback at the end of each condition.
8) Interview the parent when both conditions have finished.

In addition to the procedure above, in the AR condition, the experimenter will let the participant try out the AR system in a demonstration mode prior to the actual task. During each task, at around three minutes, the experimenter says *"Watch, something will be on the screen"*, and then reveals the extra imaginary content (bridge/track/runway) on the screen. At around four minutes, the experimenter says *"Watch, something else will be on the screen"*, and then switches the imaginary content (dusty effect/crane/fire).

5.4 Data Collection

5.4.1 Video Analysis

We analyzed participants' play behavior based on the video footage recorded during the experiment. We set two video cameras in the experiment, one in front of the participant to record the non-AR session, and one in front of the computer screen in the separate room to record the AR session.

We have reviewed the literature of play coding schemes in both general developmental psychology and pretend play with autism. Piaget [27] proposed three developmental stages of play, namely practice, symbolic and rule-based. Based on Piaget's original proposal, Smilansky [34] further developed a play category including functional play, constructive play, dramatic play and game-with-rules. Smilansky's classification has been adopted by the well-established Play Observation Scale (POS) [32] for play behavior analysis. The coding scheme commonly used in autism research (e.g. [5], [11], [22]) includes pretend play, functional play, relational play, simple manipulation/sensorimotor play, and no play. We exclude functional play because no conventional toy is included in the play material as discussed earlier.

We designed a coding scheme that includes five play categories: pretend play, constructive play, relational play, simple play and no play. The definition and examples of each category are listed below:

Pretend play (PP). Play actions that are either vehicle appropriate or novel, and involve any of the following features:

1) Object substitution: use one thing as something else (e.g. push the block along the table and make the sound *"choo choo"*).
2) Attribution of pretend properties: assign false or absent properties to an object (e.g. make one block talk to another block).
3) Imaginary object: imagine the presence of something invisible (e.g. use imaginary water to put out the fire).

Constructive play (CP). Play actions that involve creating an object or a scene with more than one object (e.g. use tube and block to build a train).

Relational play (RP). The participant manipulates more than one object or a single object in relation to others (e.g. combination, stacking, containing and arranging), but not attending to creating something or pretending something meaningful.

Simple play (SP). The participant attends to manipulating one object without purposeful meaning (e.g. moving, waving, banging, fingering, mouthing or throwing of a single object).

No play (NP). Other actions that are not play related.

We used the video editing tool Camtasia to manually annotate: (1) participant's discrete play actions relating to the play materials; (2) participant's verbal and vocal utterances; (3) experimenter's and parent's talk during the experiment. The first rater (experimenter) coded each action according to the coding scheme. We then invited an independent rater who was not aware of the hypotheses to code 10 out of total 60 video clips (randomly chosen, five from each condition) to verify the reliability of the coding scheme used. The inter-rater agreement was satisfactory (Cohen's kappa $= 0.75$).

5.4.2 Questionnaires

We used both parent questionnaire and participant questionnaire to collect qualitative feedback to evaluate the emotional quality of the participant's involvement in each condition. Given the diverse degree of behavioral disturbance of individuals with ASC, it is considered more reliable to have parents rate for engagement rather than the experimenter. Therefore, we asked each parent to observe the participant playing and rate for his/her engagement in terms of cooperativeness, attentiveness and happy smiling [30] immediately after each experiment session. We also asked the parents to provide overall feedback of the experiment after both sessions were completed. Some of the main questions in the parent questionnaire are listed below:

1) Cooperativeness or in-seat behavior (Very Good, Good, OK, Poor, Very Poor)
2) Interest or general attentiveness to the play things (Very Good, Good, OK, Poor, Very Poor)
3) Happy smiling involved in play (Frequent , Sometimes, Seldom, Never)
4) Which session do you think the participant enjoyed more? (First session, Second session, Equal, Not sure)

In addition, we asked the participants questions about their play experience and preference. We included the Fun Toolkit [29], which is a well-known survey method for young children, as part of the questions. The detailed questions are listed below:

1) How much do you like the play?

2) One thing you like about the play?
3) One thing you don't like about the play?
4) (AR condition only) Are there other things you want to be on the screen?
5) Which play is more fun (the one with/without screen)? And why?
6) Which one do you prefer to play with your friend (the one with/without screen)?

6 Experiment Results

When introduced to the AR system, all participants adapted to the mirror AR display with no difficulty except one with selective mutism who spent some extra time to get comfortable seeing himself in the screen. During the familiarisation session, all participants explored the AR augmentation mechanism by manipulating physical objects superimposed with colour blocks. They showed several autism-specific interests to AR system by inspecting related visual (e.g. put their eyes really close to the physical objects and look from unusual angles), sensorimotor (e.g. smelling and mouthing) and machinery (e.g. examining the camera) features. During the play session, all participants except two were engaged in carrying out theme-related play episodes with the AR system. We excluded these two participants data from the main results because they were not able to cooperate during the experiment due to severe impairment in language and joint attention. We present the main experiment results in this section.

6.1 Play Frequency

The action frequency of each play category among participants is normally distributed according to the Shapiro-Wilk normality test. The distributions of action frequency (occurrences per minute) in each play category are shown in Fig. 7.

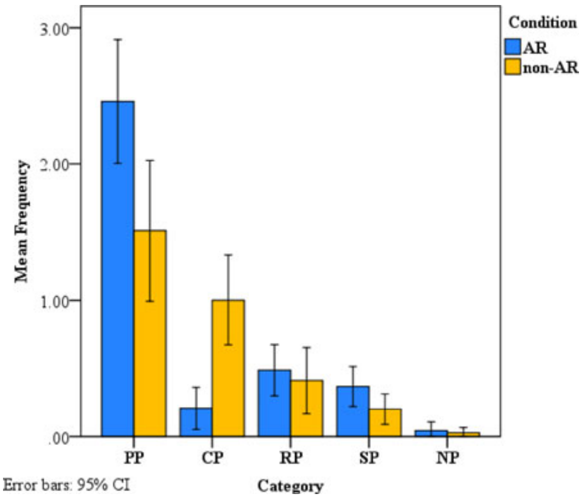


Fig. 7. Play frequency (occurrences per minute) in each category.

We can see that the mean frequency of pretend play is higher in the AR condition, while the mean frequency of constructive play is higher in the non-AR condition. The figure also shows that the level of relational play, simple play and no play remains similar in both conditions. We conducted a paired t-test evaluation and found there is a significant difference in pretend play ($t(9) = 4.66$, $p < 0.01$) and constructive play ($t(9) = -4.91$, $p < 0.01$).

To explore one indicator of the quality of pretend actions produced in both conditions, we further excluded pretend play actions with repeated play ideas. The result shows that there is still a significantly higher frequency of pretend play ($t(9) = 2.41$, $p < 0.05$) produced in the AR condition (mean = 1.79, SD = 0.68) than the non-AR condition (mean = 1.23, SD = 0.63).

6.2 Play Duration

The percentage of time spent in each type of play is illustrated in Fig. 8. As with the play frequency results, the percentage of time that participants spent in pretend play is significantly higher ($t(9) = 3.25$, $p < 0.01$) in the AR condition, while the percentage of time in constructive play is significantly higher ($t(9) = -3.49$, $p < 0.01$) in the non-AR condition. The differences among relational play, simple play and no play between the two conditions remain non-significant.

6.3 Engagement and Enjoyment

Fig. 9 shows that the mean scores of attentiveness and cooperativeness are between ok and high in both conditions, while the appearance of happy smiling for the children is between sometimes to frequent. There is a marginally significant difference in happy smiling ($z = -1.90$, *Asymp. Sig* = 0.058) using the nonparametric Wilcoxon test. According to the parent questionnaire, eight out of 10 parents thought their children were more engaged in the AR condition. One parent thought the participant was equally engaged in both conditions and one thought the participant was more engaged in the non-AR condition. Moreover, we counted how often the experimenter gave verbal prompts ("show me how to play with the block as a ...") to encourage the participant to carry on with playing. The experimenter made

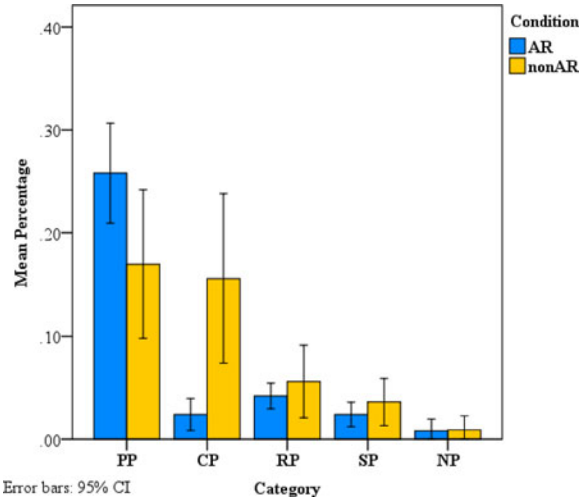


Fig. 8. Percentage of play time in each category.

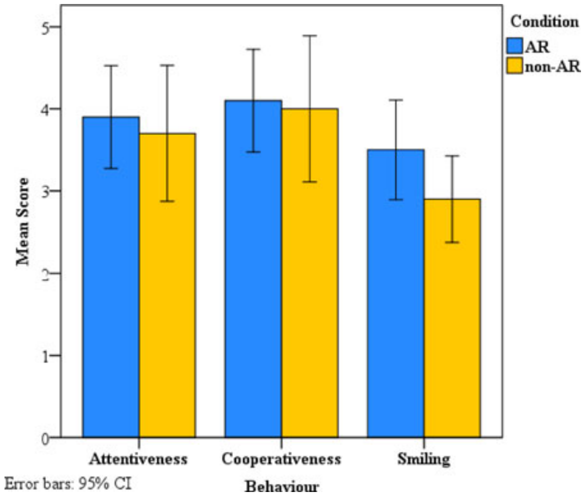


Fig. 9. The boxplot of mean score of engagement.

significantly more verbal prompts ($z = -2.61$, *Asymp. Sig* <0.01) in the non-AR condition (mean $= 0.44$) than the AR condition (mean $= 0.26$) according to the nonparametric Wilcoxon test.

The parents' feedback about participants' enjoyment is aligned with their engagement. The same eight parents thought their children enjoyed the play more in the AR condition. The average score for enjoyment is good in the AR condition and really good in the non-AR condition according to the participants' feedback. Things participants like and dislike in each condition are summarized in Table 3.

When asked which one is more fun, nine out of 10 participants chose the AR system and indicated that they would prefer the AR system to the non-AR system for play with friends. Reasons explained by the participants include: "The blocks become into different things", "It has a picture", "can see things that is not actually there", "I like seeing myself", and "It's funny". Observation shows that neither the minor lagging effect introduced by the double exponential smoothing method, nor the imperfect occlusion effect that the virtual objects occlude user's hand drew participants' attention during play. Other play objects that participants want to see on the screen include superhero, volcano, dinosaur, police office/car, people, ship, animal and ambulance.

6.4 Pretend Play Theme

During the experiment, we noticed that the themes of pretend play varied between AR and non-AR conditions even though the participants were asked to carry out the same vehicle theme at the beginning and during each task. To investigate the difference of attending to the vehicle theme indicated by the experimenter, as well as details of play ideas in terms of realistic and novel among those complying with the vehicle theme, we further categorized pretend play actions into three types:

Relevant_reality. Actions that approximate realistic behavior of the vehicle which are situationally appropriate.

Relevant_novel. Actions that involve the vehicle but are novel instead of realistic.

Not relevant. Actions that do not involve the vehicle theme indicated by the experimenter.

Table 4 shows examples of representative play ideas. Fig. 10 shows the percentage of pretend play actions in each play theme category. The mean percentages of total relevant actions including both reality-based and novel-based is significantly higher in the AR condition according to the paired t-test ($t(9) = 2.84$, $p < 0.05$). The inter-rater agreement of two raters is satisfactory (Cohen's kappa $= 0.85$).

TABLE 3
The Summary of Participants' Feedback of Like and Dislike of Each Condition

Condition	Feedback	
	Like	Dislike
AR	"a different picture on the block" "when the car gets rusty" "car get into a school" "flying" "they all change into different things"	"the train push a lot of things off the table "no police car"
non-AR	"when the goodies win" "the party" "make a lot of things using the blocks" "can rescue the car in a box" "shop keeper" "make the airplane crash"	"the baddies broke the plane" "there is no police car, no train station" "didn't know what to do" "the toy doesn't have eyes

TABLE 4
The Summary of Participants' Play Ideas in Terms of Relevance to the Suggested Vehicle Theme

Relevant		Not relevant
Realistic	Novel	
move the car along the table; move the train into the train station; make the airplane take off from the runway; point the stick at the dusty car and say "water"; put a cotton ball on the train and say "driver"; tap the finger around the car and say "fix the car"; move the train over a stick and say "train track"	move the car in the air and say "climb a tree"; make cotton balls hit the cars and say "angry bird"; make the car "go through" a tube and say "in the black hole"; tap a string around the train and say "poison the train driver"; point the two airplanes at each other and say "how's going"	party; spaceship fight; shopkeeper; make the "monster" step on things; move a string on the table and say "snake"; remove all physical props from the table and say "set off"

6.5 Individual Differences in Pretend Play

Since autism is a developmental disorder, there is a significant diversity of individual abilities such as cognition, motor control, adaptation to change and emotion regulation. These abilities largely decide the children's pretend play behaviors. After exploring the overall effect of using the proposed AR system to elicit pretend play, we analyzed the difference of the effect of the system on individual participants.

6.5.1 *Play Occurrence over Time*

In order to further investigate participants' pretend play behaviours in each condition, we calculated the average pretend play occurrence of all ten participants (P1-P10) at one minute intervals during the first five minutes of each of the three tasks.

Overall, as seen in Fig. 11, the participants' pretend play behaviour can be separated into three groups: (1) for P3, P5 and P9, there is a consistent trend that they produced more pretend play in the AR condition than the baseline non-AR condition throughout the task; (2) for P4, P6, P7, P8 and P10, they produced more pretend play in the AR condition than the non-AR condition during the majority of the five minutes' period; (3) for P1 and P2, the relative extent of pretend play actions was interleaved between conditions. As to play consistency, the pretend play produced over the five minutes' period in the AR condition remains relatively steady for the majority of participants. This could be related to the addition of new augmentations to the scene at three and four minutes respectively to keep the participants developing play ideas. There are a couple of exceptions. P6 and P10 produced much more pretend play than both the average level among participants in the AR condition and the corresponding non-AR condition at the start of play, with the amount of pretend play decreasing over time. Such intense concentration of play episodes in the early period may exhaust play ideas quickly, thus making it difficult to maintain the relatively high level throughout the task. More factors of individual differences will be discussed in the discussion session.

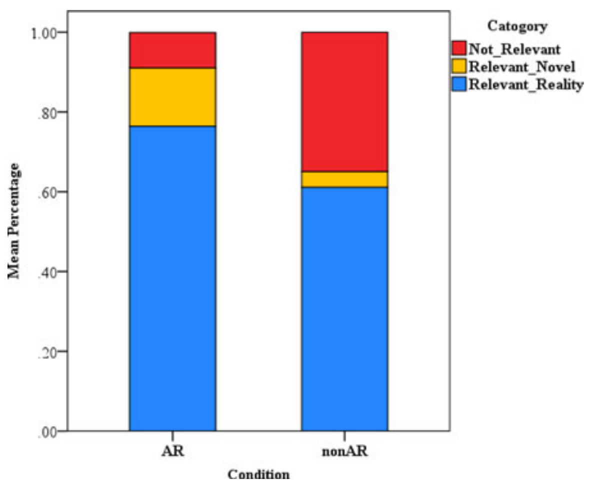


Fig. 10. The percentage of actions in terms of relevance.

6.5.2 *Non-AR Object Use*

The usage of non-AR objects is an important indicator of the potential of the AR system in generalizing pretend play to a natural environment. The number of original play ideas generated by each participant involving non-AR objects is shown in Fig. 12. For P1 and P2, more play ideas were created in the non-AR condition, but most of these were irrelevant to the play theme suggested by the experimenter. For P5 and P9, there are an equal number of ideas involving the use of non-AR objects. For P3, P4, P6, P7, P8 and P10, more non-AR object play ideas were produced while using the AR system. The factors of individual difference is further probed in the discussion session.

The results show a positive indication of an immediate generalization effect that help the participants to extend pretense ideas from those implied by the AR objects to those spontaneously generated by themselves. One of the major benefits of AR technology is that AR objects and non-AR objects co-exist in the physical world, the latter of which are common props in a natural play setup. There is, however, always concern that the salient visual effect of the AR augmentation may capture too much of the children's attention, thus reducing the potential of using non-AR objects symbolic in the play. The results demonstrate an intriguing integration and interaction between AR and non-AR objects in an open-ended play scenario.

6.6 Effect of the Condition Order

We conducted the experiment in a counterbalanced manner to control the potential learning effect introduced by a

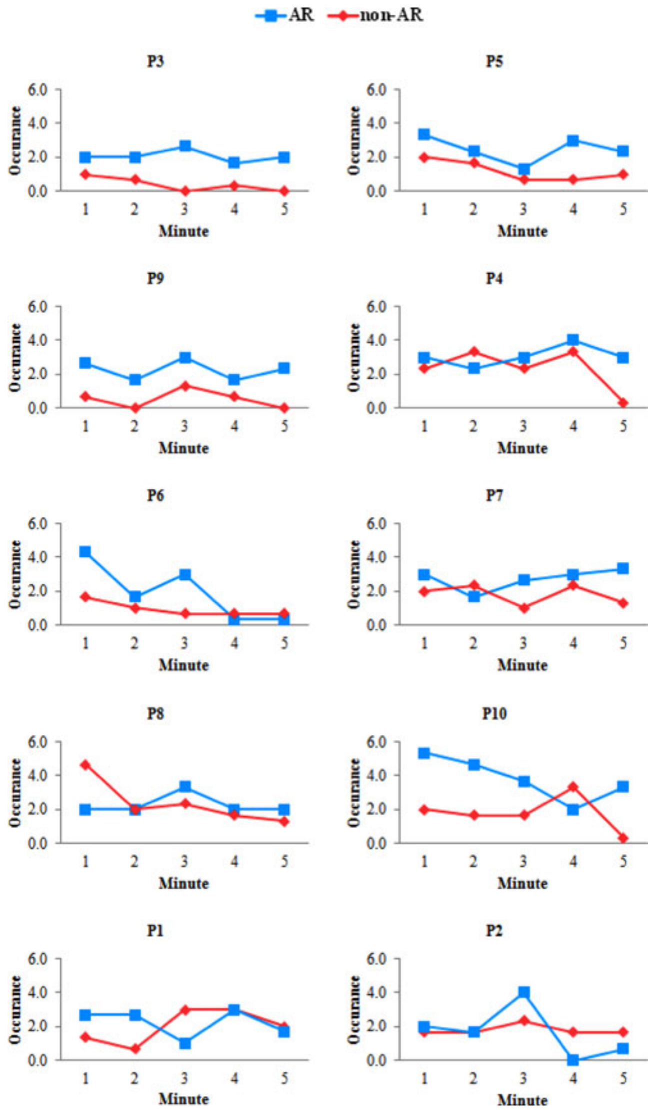


Fig. 11. The occurrence of pretend play per minutes of each participant.

particular order between the AR and non-AR conditions. We examine the main effect of condition order on the frequency of both pretend play and constructive play separately by running a univariate test. The main effect of order was not significant on either pretend play frequency ($F(1,16) = 0.19$, $p = 0.67$) or on constructive play frequency ($F(1,16) = 2.51$, $p = 0.13$). This indicates that the learning effect is efficiently controlled.

We also examined the interaction effects of condition and order on the frequency of pretend play and constructive play. Fig. 13a shows that participants who did the non-AR condition first clearly produced more pretend play in the AR condition. For those who did the AR condition first, the mean frequency of pretend play produced in the AR condition is also higher than the non-AR condition, however such difference is weaker distribution wise. As a result the interaction effect is not significant ($F(1,16) = 1.24$, $p = 0.28$). Fig. 13b shows that constructive play in the non-AR condition tends to decrease when the participants used the AR system first and there is a significant interaction between condition and order for constructive play ($F(1,16) = 8.40$, $p = 0.01$).

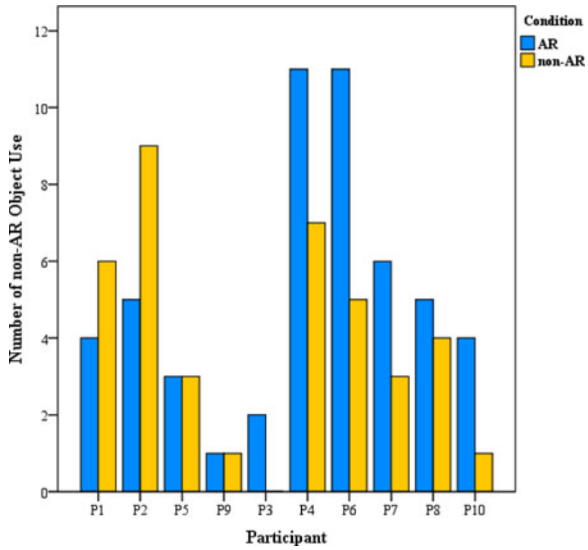


Fig. 12. Non-AR object uses of each participant.

7 Discussion

The empirical experiment confirmed readiness of children with ASC aged 4-7 to interact with the AR system with mirror display metaphor. In this section, we elaborate participants' play behaviours with the AR system and related design reflections.

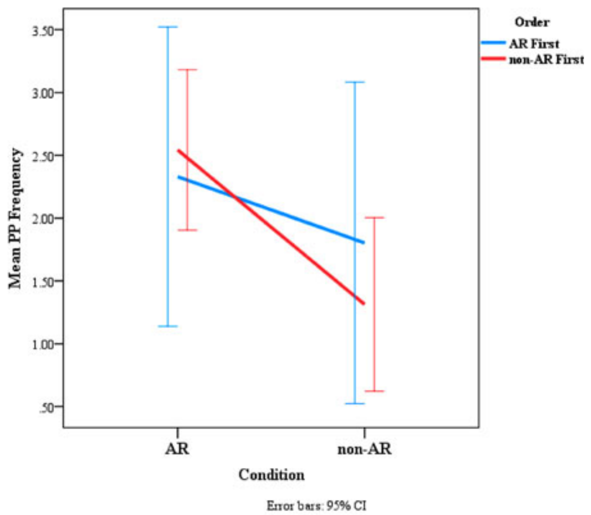
7.1 Effectiveness

7.1.1 Quantity of Pretend Play

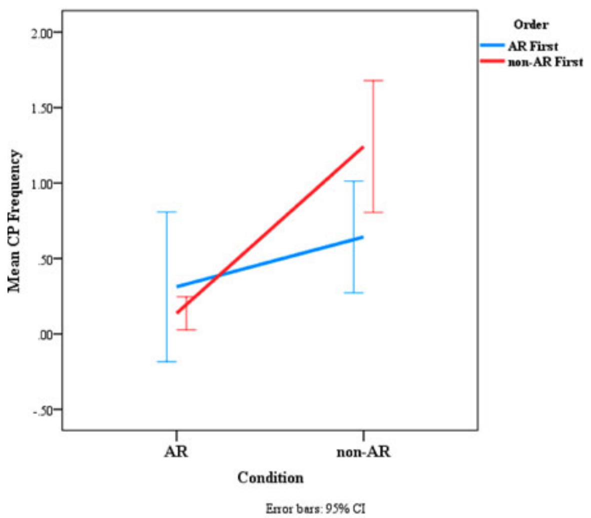
The experiment results support the hypothesis that children with ASC can carry out pretend play actions under elicited prompts, which is consistent with the existing psychology literature. In particular, the results reject both null hypotheses and demonstrate that there is a significantly higher frequency and duration of pretend play in the AR condition than the non-AR condition. This indicates a positive effect of using the AR system to promote elicited pretend play for young children with ASC. On the other hand, participants tend to produce more constructive play in the non-AR condition. This can be related to the feature of the play materials, which supports building things up in addition to pretending. Meanwhile in the AR condition, the salient visual indications given by the AR system are more persuasive for pretend play than constructive play.

7.1.2 Quality of Pretend Play

We analyzed the detailed play ideas to further investigate the quality of pretend play produced during the experiment. First, there is a noticeable difference in how participants followed the elicited play theme in each condition. As shown in Fig. 10, in the AR condition pretend play actions carried out by the participants were highly relevant to the vehicle theme of each task indicated by the experimenter. In the non-AR condition, participants tended to carry out less relevant themes. In some extreme cases, the participants ignored the experimenter's suggestions and carried out irrelevant themes (e.g. spaceship, party,



(a) Condition order effect with pretend play



(b) Condition order effect with constructive play

Fig. 13. The effect of condition and order on play.

shopkeeper, etc.) consistently across tasks. Such intense and inflexible play preference is largely due to a lack of mental flexibility [17] and restricted play interest. It is, therefore, difficult for normally developed peers to join pretend play with an autistic child, where plots are often strictly copied from things seen in movies, games or on TV, as many parents reported in this study. The inclination of following play themes with the AR system can make it an ideal platform to support and regulate shared pretend play among autistic children and their parents or peers. Second, participants produced diverse pretend play ideas relating to the indicated vehicle theme. In particular, the proportion of novel ideas to situationally appropriate ideas is relatively high in the AR condition. One potential explanation of this is that the AR system visually externalizes some internal representation of the suggested pretending theme. As a result participants have "higher bandwidth" in the working memory to get access to relevant internal representations needed to extend the play with novel ideas. One comment from a participant about the AR system is that "...(I) can remember what I might need".

7.2 Engagement

The participants' engagement is high in both setups, which could be related to the structured nature of the experiment. Parents' feedback shows that participants are more engaged in the AR condition. Although we should be cautious interpreting such feedback, the significantly lower frequency of experimenter's verbal prompting also indicates that participants are more engaged in the AR than the non-AR condition. Although the system demonstration session at the beginning of the AR condition is meant to reduce the novelty effect of the AR technology, it is still likely to be one of the motivational factors. This is further indicated by the result that the majority of participants thought the AR session is more fun and preferred to play it with their friends according to the children questionnaire.

7.3 Individual Differences

Different people with autism show different level of deficit or delayed development under the autism spectrum, and lack of imagination is only one of the many autistic traits. This makes the "one treatment for all" approach almost impossible. Nevertheless by analyzing the individual performance difference, it helps us obtain a better understanding of the potential user group that will benefit most by using the AR system to improve pretend play.

The combined results of pretend play occurrence over time and object use indicates an interesting pattern among the participants. P1 and P2 show frequent symbolic play at home according to the parent questionnaire and interview. During the experiment they showed a minimal difference in pretend play produced per minutes in the AR and non-AR conditions, and they tend to develop more pretense ideas involving non-AR objects in the non-AR condition. In the non-AR condition, both P1 and P2 carried out the same theme repetitively throughout the three tasks regardless of the vehicle-related theme suggested by the experimenter. However in the AR condition, due to the salient visual indication, they tended to adapt to the theme switching and produce more theme-relevant play ideas than in the non-AR condition. The results imply that the AR system might not help to further improve pretend play of those who tend to engage with such play in their daily repertoire. It may, however, play an effective role in helping children to adapt to new themes beyond their restricted interest.

P3, P5, and P9 seldom engage with symbolic play at home according to the parent questionnaire and interview. During the experiment, all of them consistently produced more symbolic play during each one minute interval in the AR condition than the non-AR condition. In terms of object usage, they seldom used non-AR objects in either conditions comparing with the rest of the participants. Since object use is the closest reflection of the level of pretend play in a natural setup, such results indicate the AR system has the most positive effect upon participants who have the most developmental delay in overall pretend play performance, although very little improvement in the use of non-AR object occurs.

For the remaining five participants, four of them were reported to occasionally carry out symbolic play while the remaining one was reported as "frequently". Results show that they produced overall more symbolic play in the AR condition during the five minute period, although this pattern is less consistent than those with severe symbolic play impairments. In addition, there is an apparent improvement of use of non-AR objects in the AR system. It shows a very positive effect on the majority of the participants under a short exposure, which is rather encouraging.

7.4 Skill Transfer

Fig. 13 shows that participants who use the AR system first tend to be less engaged with constructive play activities, which suggests that one effect of the AR system is to discourage constructive play, thus allowing the participants to focus more on potential pretend play. On the other hand, when the participants followed the non-AR and then AR condition order, there is an obvious inclination that participants produced more pretend play using the AR system. This tendency of pretend play increase in the second condition, however, gets disrupted among participants who were introduced to the AR system first. The most likely explanation is that participants' pretend play behaviours are positively influenced by using the AR system and they carried it into the later play in the non-AR condition, thus the pretend play difference between the two conditions was mitigated to some noticeable extent. In other words, there might be a positive skill transition occurring from the AR to non-AR condition. Although we have to be careful when interpreting such skill transfer due to the short-term nature of the study and the variation of autism spectrum condition, such preliminary results are still informative for future studies involving larger sample sizes and long-term intervention evaluation.

7.5 Design Reflections

7.5.1 Re-Examine Usability

The experiment demonstrates that participants can successfully interact with the AR system, even though seven out of 10 participants were reported to have poor fine motor skills including eye-hand coordination tasks (e.g. handwriting). Some usability issues perceived during the experiment include:

Hand over marker. Participants were told to hold the block instead of the marker cube when manipulating the AR object during the familiarisation session. Even under physical prompting, some participants persevered with holding the marker cube which caused the virtual object to flicker.

Inward/Outward orientation. As discussed in the pilot study, most participants have to spend extra time exploring the spatial relationship in order to align objects properly with virtual objects registered on the table (e.g. a virtual bridge) due to the inward/outward reversal caused by the mirrored view.

Limited size of play area. The taped play area can be very crowded when it is occupied with AR and non-AR objects.

These usability issues involve trade-offs between high tracking accuracy/extensibility, avoiding occlusion of placing a marker on the table and high tracking reliability respectively. For the second issue, we may improve the situation by drawing a physical marker (e.g. a dot) on the table to indicate the center location of the virtual objects, and include virtual objects registered on the table surface in the familiarisation session.

7.5.2 Adapt to the Real World

The current AR system is designed as an experimental apparatus. Therefore, it only provides a small set of AR props and three fixed play themes. In order to scaffold pretend play development beyond the laboratory setup, we proposed the following improvements:

Provide more AR props. Most children with ASC have a very restricted interests. Therefore the availability of their desired play theme can be an important motivation. The participant and parent interviews provided a rich set of AR props that might also be included, including superheroes, dinosaur, people, baby, police car/office, ship, animal, emergency vehicle, and characters from popular film/game/TV program.

Assign augmentation to the AR object. This might encourage children not only to develop ideas about how to pretend, but also proactively choose what to pretend.

Fade out visual effect. In order to gradually bridge the pretend play experience from the AR system to real life scenarios, a fading out mechanism could be implemented for the visual effect, which is based on the most-to-least prompt strategy commonly used in applied behavioral approach.

Enable the user to record the play. Recording is a common feature for storytelling systems (e.g. [33]). Several participants in the experiment, in their spare time browse online videos for game demonstrations (e.g. Minecraft, Super Mario) and two participants particularly mentioned that they would like to share the play they made in the AR session online with other children.

7.5.3 Reflections on System and Experiment Design

Based on the current study, we suggest a two-tier approach when designing AR systems and experiments for children with pervasive developmental disorders such as ASC:

Design for the target deficit. A thorough literature review on the target developmental disorder is required during the early design phase. Investigating theoretical explanations of the deficit provides critical reference about the potential positive effect of using AR technology. Although the novelty of AR technology is a motivational merit, it is expected to fade out over time. It is therefore advisable to focus on how the unique nature of AR technology can best eliminate the specific deficit from a mechanism level. In addition, both theory and intervention methods provide extensive references for system design and evaluation approach.

Consideration for autistic characteristics. While the effectiveness of an AR system is largely determined by its design to reinforce the target cognition/behavior, the usefulness of the system is a prerequisite to achieve that. We summarized a list of pervasive disorders that must be considered when designing AR systems and experiments for children with ASC:

1) *Language delay and impaired joint attention*. It is difficult to explain things like how to interact with the AR system and what one is expected to do during the experiment, to children whose language and joint attention are severely impaired. For task-oriented AR systems,

the researcher/designer has to carefully determine the developmental level of the target group.

2) *Restricted interest*. It is difficult to persuade children with autism to take part in activities that they are not interested in. Besides the novelty of AR technology, the content of the AR system has to be appealing in order to keep the children engaged for any length of time, which ideally requires a selection of available AR objects of different types, shape, color, etc.
3) *Resistance to change*. Most children with ASC follow a strict routine for daily activities and easily become anxious when new activity is introduced—for example when visiting an unfamiliar environment. In order to eliminate withdrawal caused by the above reasons, we decided to meet the participants before the study by running a home interview, so that the participants can become familiar with the experimenter ahead of time. We also prepared visual guidance to help the parents describe the study to their children.

7.6 Study Limitations and Future Work

Beyond the technical restraints discussed in the previous section, there are several study limitations that we expect to explore in future. First, although the preliminary study results demonstrate a positive effect of elicited pretend play with the AR system, the potential generalization effect to improve spontaneous pretend play in real life is still to be examined with systematic intervention methods over a longer period of time. Second, although the familiarization session at the beginning of the AR condition helps participants explore the mechanism of AR, technical novelty may still have been one of the motivational factors in our study. Thus engagement of pretend play over longer system exposure is another topic to be probed in the further study. Third, the current study only examined using the AR system for solitary pretend play. Development of shared pretend play involving social context is an important next step. As discussed in the previous section, the AR system naturally supports multi-user interaction and potentially directs mutual play themes among users. Fourth, the current vehicle play themes are more appealing to boys and most of the participants signed up for the study are boys. Therefore the outcome of the study has a potential gender bias. More girl-friendly and mutual themed AR objects should be added and the effect with girls should be explored accordingly.

8 Conclusion

We presented the design and evaluation of an AR system aiming to promote open-ended pretend play for young children with ASC. Results indicate a positive effect of increased elicited pretend play in frequency, duration and relevance with the AR system compared with a non-computer setup. Participants were highly engaged with the AR system and produced a diverse range of play ideas. Individual differences among participants predict a gradual effectiveness for children in different autistic conditions. The AR system tends to have the most positive effect on children who have the most developmental delay in pretend play. And for children who carry out pretend play at home, the AR system may not provide further enhancement in the frequency of pretend play, but the salient visual effect may be persuasive in adapting to new themes beyond their restricted interests. In addition, we discussed skill transfer, usability and limitation of the AR system and summarized guidance for designing and evaluating AR systems for children with ASC and general pervasive developmental disorders based on existing literature. Moreover, our study demonstrated a procedural approach to exploring the potential of AR technology in stimulating specific cognitive activities like pretend play for challenging user groups like young children with ASC.

Acknowledgments

The authors would like to thank Dr. N. Yuill and colleagues in the ChatLab, Dr. W. Farr, Dr. J. Newman, Dr. E. Hill, Dr. J. Good and local autism event organizers for giving invaluable feedback as the study progresses. We also would like to thank the Cambridge Autism Research Center and National Autistic Society Cambridge branch for helping advertise the recruitment. In particular, we would like to thank all participants' families for taking part in the study and the two independent raters who kindly helped with the video coding. Z. Bai is the corresponding author.

References

[1] "American psychiatric association," in *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed., Text Rev. Washington, DC, USA: American Psychiatric Association, 2000.
[2] D. Bergen, "The role of pretend play in children's cognitive development," *Early Childhood Research & Practice*, vol. 4, no. 1, pp. 2–13, 2002.
[3] Z. Bai, A. F. Blackwell, and G. Coulourism, "Through the looking glass: Pretend play for children with autism," in *Proc. IEEE Int. Symp. Mixed Augmented Reality*, Oct. 2013, pp. 49–58.
[4] S. Baron-Cohen, A. M. Leslie, and U. Frith, "Does the autistic child have a "theory of mind"?" *Cognition*, vol. 21, no. 1, pp. 37–46, 1985.
[5] S. BaronCohen, "Autism and symbolic play," *Brit. J. Developmental Psychol.*, vol. 5, no. 2, pp. 139–148, 1987.
[6] S. Baron-Cohen and S. Wheelwright, "Obsessions' in children with autism or Asperger syndrome. Content analysis in terms of core domains of cognition," *Brit. J. Psychiatry*, vol. 175, no. 5, pp. 484–490, 1999.
[7] S. Baron-Cohen, "Instructed and elicited play in autism: A reply to Lewis and Boucher," *Brit. J. Developmental Psychol.*, vol. 8, p. 207, 1990.
[8] E. E. Barton and M. Wolery, "Teaching pretend play to children with disabilities: A review of the literature," *Topics in Early Childhood Special Educ.*, vol. 28, pp. 109–125, 2008.
[9] B. Brederode, P. Markopoulos, M. Gielen, A. Vermeeren, and De H. Ridder, "pOwerball: The design of a novel mixed-reality game for children with mixed abilities," in *Proc. Conf. Interaction Des. Children*, Jun. 2005, pp. 32–39, .
[10] X. Casas, G. Herrera, I. Coma, and M. Fernndez, "A Kinect-based augmented reality system for individuals with autism spectrum disorders," in *Proc. Int. Conf. Comput. Graphics Theory Appl. Int. Conf. Inform. Vis. Theory Appl.*, 2012, pp. 440–446.
[11] T. Charman and S. Baron-Cohen, "Brief report: Prompted pretend play in autism," *J. Autism Develop. Disorders*, vol. 27, no. 3, pp. 325–332, 1997.
[12] A. G. D. Corrła, I. K. Ficheman, M. do Nascimento, and R. de Deus Lopes, "Computer assisted music therapy: A case study of an augmented reality musical system for children with cerebral palsy rehabilitation," in *Proc. 9th IEEE Int. Adv. Learn. Technol.*, Jul. 2009, pp. 218–220.
[13] L. Escobedo, D. H. Nguyen, L. Boyd, S. Hirano, A. Rangel, D. Garcia-Rosas, M. Tentori, and G. Hayes, "MOSOCO: A mobile assistive tool to support children with autism practicing social skills in real-life situations," in *Proc. SIGCHI Conf. Human Factors Comput. Syst.*, May 2012, pp. 2589–2598.

[14] W. Farr, N. Yuill, and S. Hinske, "An augmented toy and social interaction in children with autism," *Int. J. Arts Technol.*, vol. 5, no. 2, pp. 104–125, 2012.
[15] M. Fiala, "Magic mirror system with hand-held and wearable augmentations," in *Proc. IEEE Virtual Reality Conf.*, 2007, pp. 251–254.
[16] G. Herrera, F. Alcantud, R. Jordan, A. Blanquer, G. Labajo, and C. De Pablo, "Development of symbolic play through the use of virtual reality tools in children with autistic spectrum disorders two case studies," *Autism*, vol. 12, no. 2, pp. 143–157, 2008.
[17] E. L. Hill, "Executive dysfunction in autism," *Trends in Cognitive Sci.*, vol. 8, no. 1, pp. 26–32, 2004.
[18] H. Hong, H. Y. Jeong, R. I. Arriaga, and G. D. Abowd, "TriggerHunter: designing an educational game for families with asthmatic children," in *Proc. CHI'10 Extended Abstracts Human Factors Comput. Syst.*, Apr. 2010, pp. 3577–3582.
[19] [Online]. Available: http://www.who.int/classifications/icd/en/GRNBOOK.pdf, 1993.
[20] [Online]. Available: http://goblinxna.codeplex.com/, 2012.
[21] [Online]. Available: http://virtual.vtt.fi/virtual/proj2/multimedia/alvar, 2012.
[22] C. Jarrold, J. Boucher, and P. K. Smith, "Generativity deficits in pretend play in autism," *Brit. J. Developmental Psychol.*, vol. 14, no. 3, pp. 275–300, 1996.
[23] C. Jarrold, "A review of research into pretend play in autism," *Autism*, vol. 7, no. 4, pp. 379–390, 2003.
[24] A. M. Leslie, "Pretense and representation: The origins of" theory of mind"," *Psychol. Rev.*, vol. 94, no. 4, pp. 412–426, 1987.
[25] T. Luckett, A. Bundy, and J. Roberts, "Do behavioural approaches teach children with autism to play or are they pretending?" *Autism*, vol. 11, no. 4, pp. 365–388, 2007.
[26] O. Oda, L. J. Lister, S. White, and S. Feiner, "Developing an augmented reality racing game," in *Proc. 2nd Int. Conf. INtell. TEchnol. Interactive Entertainment*, Jan. 2008, p. 2.
[27] J. Piaget, *Play, Dreams and Imitation in Childhood*. Evanston, IL, USA: Routledge, vol. 25, 2013.
[28] I. Radu and B. MacIntyre, "Using children's developmental psychology to guide augmented-reality design and usability," in *Proc. IEEE Int. Symp. Mixed Augmented Reality*, Nov. 2012, pp. 227–236.
[29] J. C. Read and S. MacFarlane, "Using the fun toolkit and other survey methods to gather opinions in child computer interaction," in *Proc. Conf. Interaction Des. Children*, Jun. 2006, pp. 81–88.
[30] E. Richard, V. Billaudeau, P. Richard, and G. Gaudin, "Augmented reality for rehabilitation of cognitive disabled children: A preliminary study," in *Proc. Virtual Rehab.*, Sep. 2007, pp. 102–108.
[31] C. B. Riguet, N. D. Taylor, S. Benaroya, and L. S. Klein, "Symbolic play in autistic, Down's, and normal children of equivalent mental age," *J. Autism Developmental Disorders*, vol. 11, no. 4, pp. 439–448, 1982.
[32] K. H. Rubin, "The play observation scale (POS)," Univ. of Waterloo, 1989, http://www.rubin-lab.umd.edu/CodingSchemes/POS%20Coding%20Scheme%202001.pdf
[33] K. Ryokai and J. Cassell, "StoryMat: A play space for collaborative storytelling," in *CHI'99 Extended Abstracts Human Factors Comput. Syst.*, May, 1999, pp. 272–273.
[34] S. Smilansky, *The Effects of Sociodramatic Play on Disadvantaged Preschool Children*. Hoboken, NJ, USA: Wiely, 1968.
[35] A. Tartaro and J. Cassell, "Authorable virtual peers for autism spectrum disorders," in *Proc. 17th Eur. Conf. Artif. Intell. Combined Workshop Lang.-Enabled Educ. Technol. Dev. Eval. Robust Spoken Dialogue Syst.*, Aug. 2006.
[36] L. Wing and J. Gould, "Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification," *J. Autism Developmental Disorders*, vol. 9, no. 1, pp. 11–29, 1979.

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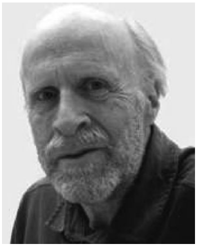

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